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SUSTAINABLE MACHINING BY OPTIMIZING THE POWER DEMAND THROUGH DRY TURNING OF 316L STAINLESS STEEL

Rusdi Nur
Department of Mechanical Engineering, Politeknik Negeri Ujung Pandang, Makassar, Indonesia
E-Mail: rusdinur@poliupg.ac.id

ABSTRACT

This paper presents the experimental results from modelling and optimization of cutting conditions when turning processes of AISI 316 stainless steel using a central composite design (CCD). Type of AISI 316L, a series of stainless steel, is typical as medical grade that occur difficulties in machining. Power demand and tool life were measured, analyzed and modelled. The results of this experimental work show that the cutting speed has a significant effect on machining responses (power demand and tool life) compared with feed, and that optimum machining parameters was obtained, while following towards sustainability were in terms of minimizing power demand, extending of tool life and improving productivity. The models developed were used for evaluating and optimizing the input process, to obtain optimum machining responses for an overall process improvement.

Keywords: power demand, tool life, turning, and stainless steel.

INTRODUCTION

Machinability is the ability of a material to be machined. Machinability is a term indicating how the work material responds to the cutting process [1]. In the most general case, good machinability means that material is cut with good surface finish, long tool life, low force and power requirements, and low cost. Some researchers have performed investigations on various aspects related to the turning process, i.e. dry turning of AISI 1010 [2] and nitrogen alloyed duplex SS [3], hard turning of AISI H13 steel [4] and MDN250 [5], and turning of AISI 1040[6], etc. The machining process as essential in manufacturing activities that providing input to the global economic growth [7]. The other sides, intensive research work in the machining process improves machining performances through higher machining performances [8]. Therefore, in nowadays more and more important become environmentally and health benign technologies and advanced techniques for achieving cleaner, healthier, safer, and economical machining process. That view presents sustainable machining, through improved information about the environmental impacts of existing manufacturing processes and develops new technological concepts [9, 10].

Sustainable in manufacturing is currently a very important issue for governments and industries worldwide [11]. Sustainable manufacturing must respond to challenge of economical, environmental and social [12]. Most of the manufacturing industries are using mechanical machining which became a big contribution in the demand for energy.

This study presents the approach for optimized the cutting parameters in turning process, based on minimum power demand and longest tool life. This paper makes a contribution to the machining process for minimized the power demand there from generating in reducing emissions.

POWER DEMAND

In the machining process, a number of studies have been carried out, but environmental issues are rarely considered except for the work done by [13], which studied the electrical energy requirements in the milling process. Their approach can be used to evaluate energy consumption in machining processes. Following on earlier their work, the electrical power required, *P*, for machining can be calculated from the equation as follow:

$$P = P_o + k \cdot \dot{v} \qquad (1)$$

where, *P* is the power [W] required by machining process, P_o is the power [W] required by all machine modules for a machine operating without loading, *k* is the specific energy requirement [Ws/mm^3] in cutting operations, and $\dot{v}$ is the material removal rate (MRR), in [mm^3/s]. Value of $k \cdot \dot{v}$ can be summarized as the cutting power.

EXPERIMENTAL DESIGN

Materials and cutting tool

In this study, Austenitic stainless steel AISI 316L with a diameter of 150 mm and length of 300 mm will be used as the workpiece material in the turning process. Detail composition of AISI 316L and some general properties of AISI 316L are shown in Table-1.

The machining test was conducted using the ALPHA 1350S 2-axis CNC lathe machine (8.3 kW of house power and the spindle speed ranges from 100 to 6000 rpm) without fluid. The cutting tool inserts were placed on the tool holder designated as TCLNR 2020K12.

Experimental setup

The experimental setup was developed using Design-Expert software version 7.1. The total number of experiments was eleven as shown in Table-2, where the midpoint was replicated twice to determine the pure error.

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Table-1. Composition of AISI 316L.

Items	Min	Max
C	-	0.03
Mn	-	2
Si	-	0.75
P	-	0.045
S	-	0.03
Cr	16	18
Mo	2	3
Ni	10	14
N	-	0.1

Table-2. Cutting parameters.

Levels	Low (-1)	Centre (0)	High (+1)
Cutting speed (m/min)	90	150	210
Feed (mm/rev)	0.10	0.16	0.22
Depth of cut (mm)	0.4		
Coolant	No Fluid		

RESULTS AND DISCUSSIONS

The experimental results for power demand and tool life are shown in Figure-1and Figure-2.

Power demand

The relationship between the power demand and feed for various cutting speeds was shown in Figure-1. It can be clearly seen that the power demand increases with the increasing cutting speed but the feed rate of increase was generally similar. It was confirmed by [14] stated that the power consumption continuously increase with increasing cutting speed when machining of AISI 1045 steel. Increasing the cutting speed on machining will be more required power consumed to rotate the spindle motor.

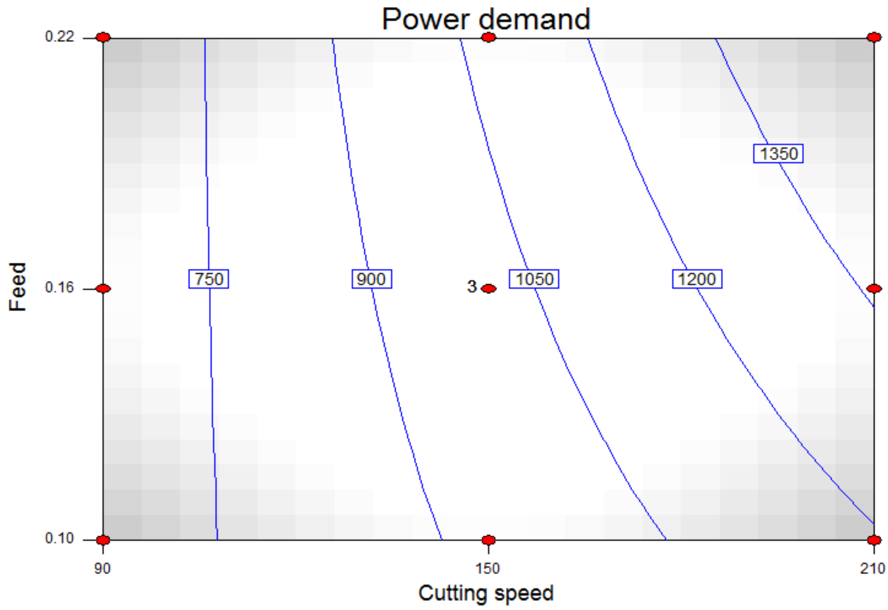

Figure-1. Plotting contour of power demand.

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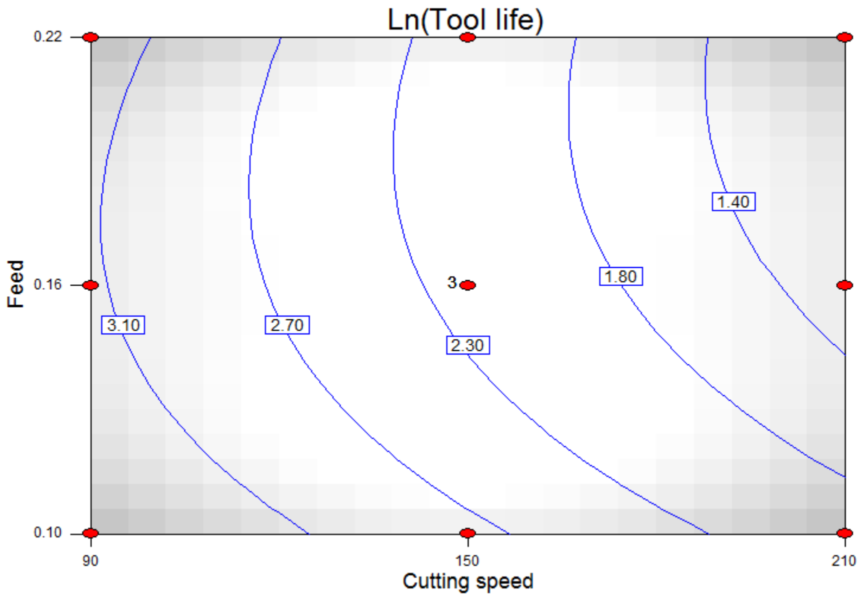

Figure-2. Plotting contour of tool life.

Tool life

The influence of cutting speed and feed rate on the tool life is shown as Figures-2. It showed that the tool life would be decrease for increasing of cutting speed and feed rate. These result was confirmed by [15], it was noticed that with the increasing cutting speed the tool life decreases for each of the feeds when turning of duplex stainless steel using CVD coated carbide (CTC 1135). This phenomenon was due to increasing the cutting speed increases the intensity of wear of the cutting edge. Another confirmation of [16], it founded that tool life reduced with an increase in cutting speed, most likely due to the increased temperatures generated.

Optimization

The analysis of variance (ANOVA) table for the model of power demand and tool life was shown in Table-3. It indicates the p-value as < 0.0001 which was much lower than the significant level of 0.05. Therefore, from the statistical point of view, this linear and quadratic model was valid.

Table-3. ANOVA analysis for power demand and tool life.

Source	Sum of squares	Degree of freedom	Mean square	F Value	Prob > F
Power Demand					
Model	8.297E+005	3	2.766E+005	64.14	< 0.0001
Vc	7.568E+005	1	7.568E+005	175.52	< 0.0001
F	34916.41	1	34916.41	8.10	0.0248
Vc* f	37999.65	1	37999.65	8.81	0.0208
Tool Life					
Vc	5.46	1	5.46	1377.61	< 0.0001
f	0.64	1	0.64	161.24	< 0.0001
f^2	0.20	1	0.20	49.66	0.0004
*Vc*f*	0.16	1	0.16	39.28	0.0008

As shown in Table-3, it indicates the p-value as < 0.0001 which was much lower than the significant level of 0.05. Therefore, from the statistical point of view, this linear and quadratic model was valid. Thus, the final equation is obtained in actual factors based on empirical models as below:

$$P = +566.15 + 1.59*Vc - 2789.73*f + 27.07*Vc*f \quad (2)$$

$$Ln(T) = +6.04 - 7.13E\text{-}03*Vc - 21.10*f + 74.63*f^2 - 0.06*Vc*f \quad (3)$$

where *Vc* is cutting speed (m/min) and *f* is feed (mm/rev).

The output response can be determined by the influence of each input parameter was measured. It can be performed with creating a model to optimize the range of cutting speed and feed, which will be obtained criteria of power demand and tool life were desired. These criteria were complemented the combination of cutting speed and feed and shown in the gray zone of plotting overview (Figure-4). The obtained solution was intersection between the power demand criteria (zone left next to the contour P of 750W) and the tool life criteria (zone under the contour T of 25.79 minutes).

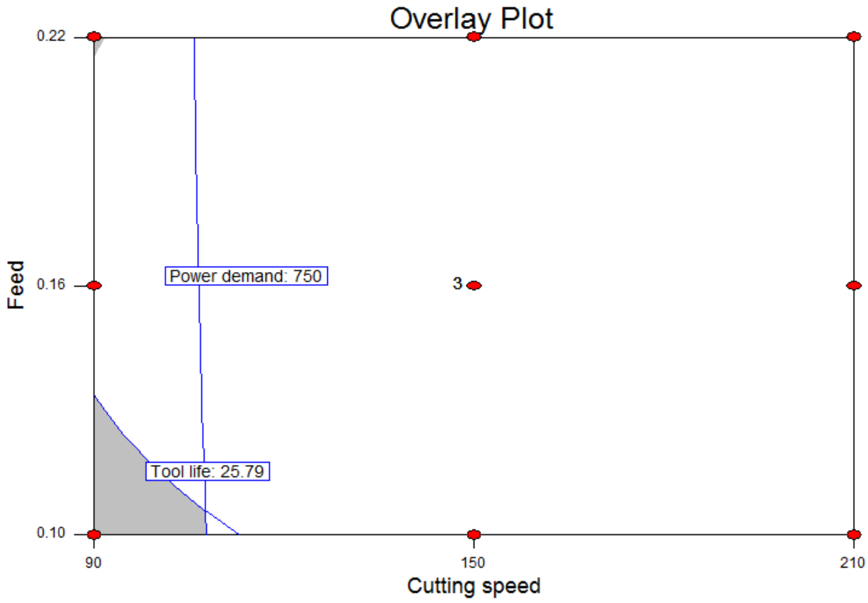

Figure-3. Plotting overlay of the cutting parameters for maximum criteria of 750W-power demand and 25.79 minutes-tool life.

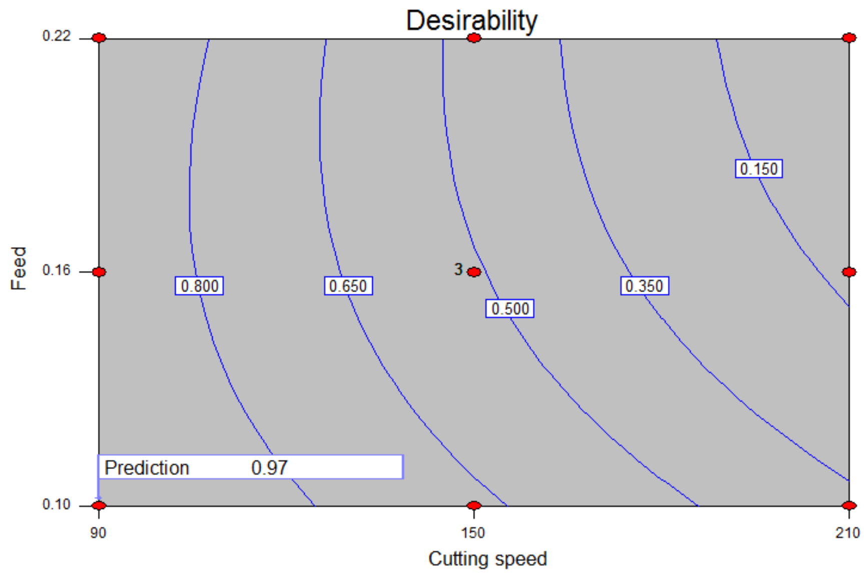

Figure-4. Desirability overview of the input parameters to optimize the power demand and tool life.

The achieved solution can be determined by more particular the responses criteria. This arrangement can be utilized to acquire the minimun of power demand and the longest of tool life, by calculating the desirability from the resulting equations. The calculation indicates that the maximum value of desirability was attained at the low of cutting speed (90 m/min) and feed (0.10 mm/rev) as given in Figure-5. This result was confirmed by [17] in their paper, it stated that value desirability was found at low feed rate when turning of treated Al-11%Si alloy using TiN coated carbide.

CONCLUSIONS

Investigating the turning of AISI 316L Stainless Steel using an uncoated cemented carbide with different cutting speed (90, 150 and 210 m/min) and feed (0.10, 0.16 and 0.22 mm/rev), it was concluded that power demand increases with the increase of the cutting speed and decrease of the feed for particular machining. Finally the optimal of cutting conditions in terms of power demand and tool life was obtained to be in the low level for both of cutting speed and feed.

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